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Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

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PROJECT APOLLO

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By Contingency Analysis Section
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CONTENTS

CREW CHARTS

FIGURES

RATIONALE FOR USING THE SATURN MONITOR AND ABORT CREW CHARTS FOR APOLLO 11 (MISSION G)

By Contingency Analysis Section

1.0 SUMMARY

The purpose of this document is to explain the crew charts that the Flight Analysis Branch has prepared for Apollo 11 (Mission G). The operational abort plan for Apollo 11 (Mission G) (ref. 1) includes a complete description of abort modes, philosophy, and constraints used in the gereration of these crew charts.

The following sections include copies of the applicable crew charts as well as a discussion of the situations that require their use. Finally, the procedure for using each of the charts is included.

2.0 INTRODUCTION

The crew charts contained in this document were prepared by the Flight Analysis Branch for the G mission launched July 16, 1969. Changes required to update the crew charts because of variations in launch date are discussed in each section where applicable. The crew charts included are listed below along with the responsible Flight Analysis Branch personnel.

(a) Launch abort, section 4.0: E. M. Henderson

(b) TLI monitoring, section 5.1: C. T. Hyle

(c) TLI abort, section 5.2: C. J. Laetz

(d) LOI abort, section 6.0: C. E. Foggatt

3.0 ABBREVIATIONS

CM	command module
CMC	command module computer
COAS	crew optical alinement sight
COI	contingency orbit insertion
CSM	command and service modules
DPS	descent propulsion system
DSKY	display keyboard
DVM	ΔV magnitude
EMS	entry monitoring system
EPO	earth parking orbit
ESS	early S-IVB staging
FDAI	flight director attitude indicator
g	entry load
g.e.t.	ground elapsed time
h	altitude
IGA	inner gimbal angle
IMU	inertal measurement unit
IU	instrument unit
LOI	lunar orbit insertion
LOI-1	first LOI burn into a 60- by 170-n. mi. altitude orbit
LOI-2	lunar orbit circularization burn into a 60-n. mi. altitude orbit
MCC	midcourse correction

MGA	middle gimbal angle
MSFN	Manned Space Flight Network
OGA	outer gimbal angle
RCS	reaction control system
REFSMMAT	transformation matrix from inertial to stable member (IMU)
SC	spacecraft
S-IC	launch vehicle first stage
SCS	stabilization and control subsystem
S-II	launch vehicle second stage
S-IVB	launch vehicle third stage
SPLERROR (ΔR)	difference between the onboard predicted landing point and the mode III target point
SPS	service propulsion subsystem
TAR	time from abort to reentry
THC	translational hand controller
TLC	translunar coast
TLI	translunar injection
t_B	burn time
t_{ff}	time of free fall
t_{IG}	time of ignition
V_i	inertial velocity
ΔR	SPLERROR
ΔV	total sensed velocity change

Subscripts:

p perigee

IG ignition

i inertial

b body axis system

4.0 LAUNCH PHASE CHARTS

To facilitate trajectory monitoring during the launch phase, the crew uses the FDAI and DSKY displays with two onboard crew charts. The first chart (crew chart 1) presents the nominal launch profile along with the abort trajectory limits and the orbital capability regions. This chart would be used by the crew to help determine when an abort would be required for trajectory deviations and to determine what action (abort mode) would be required if an abort should occur. Normally, the ground control will inform the crew when trajectory limits are violated and will advise the crew on the appropriate abort action. However, if voice communications were lost during launch, the crew would have to depend on crew chart 1 and on the onboard displays for this information. The second chart (crew chart 2) lists the planned trajectory parameters for the nominal launch. This chart will be used by the crew to monitor the trajectory parameters during launch, and the data would provide the launch vehicle steering parameters if the crew manually takes over after a launch vehicle platform failure during the S-II and the S-IVB portions of the launch.

The nominal launch profile and the associated abort trajectory limits and capability lines are shown as functions of inertial velocity and altitude rate in crew chart 1. The chart has a dual function.

(a) To determine when an abort is necessary for trajectory deviations

(b) To determine what capability exists if the launch vehicle shuts down

For the first function, if the actual flight trace violates the structural limit, the heating limit (invalid for engine out), or the 16g maximum entry load factor limit, the crew would be required to initiate an abort. If the trace approaches the 100-second free-fall limit, the crew would initiate an abort when the DSKY display of free-fall time is 100 seconds and decreasing. Note that the ground control normally would inform the crew both by voice and by command of the abort light for trajectory violations if voice communications and command capability exist.

For the second function of the first chart (i.e., to determine what capability exists if the launch vehicle shuts down), several possibilities exist based on the boundaries crossed by the flight trace.

(a) ESS to COI tick - the crew could manually upstage to the S-IVB and could achieve the mode IV COI region.

(b) ESS to orbit tick - the crew could manually upstage to the S-IVB and achieve earth parking orbit.

(c) Mode IV, COI boundary - the crew could use the SPS manually to achieve orbit (either a two-impulse, a single impulse, or an apogee kick maneuver).

(d) Mode II/mode III line or $\Delta R > -400$ n. mi. - if a suborbital abort were required, the crew would use lift control or an SPS burn or both to obtain an Atlantic landing.

(e) GO/NO-GO line - no action would be required by the crew (except for an overspeed); a safe orbit has been achieved; $h_p > 75$ n. mi. Again, these capabilities would be relayed from ground control when voice communications exist.

The second chart for the launch phase, crew chart 2, lists the SC IMU pitch gimbal angle, inertial velocity, altitude rate, and altitude as functions of ground elapsed time for the nominal planned profile. These parameters will be compared to the actual flight values as an estimate of the trajectory status during the launch. The primary function of this chart will be to provide crew steering parameters if a manual takeover should occur (stick steering) after launch vehicle IU platform failure. The SC computer will provide steering commands for the first stage (S-IC) portion of the flight and the crew will manually provide steering commands for the second and third stage (S-II and S-IVB) portions of the launch. The crew will use the parameters in crew chart 2 in conjunction with the FDAI and DSKY displays. After comparison of the inertial velocity on the DSKY with the inertial velocity on the chart, the crew will command the appropriate pitch gimbal angle to achieve the desired altitude rate and altitude profile and will continually check the results with the chart until orbital insertion is achieved. Note that this procedure and these parameters assume a normally functioning launch vehicle except for the platform failure.

5.0 TRANSLUNAR INJECTION CREW CHARTS

5.1 Translunar Injection Monitoring

Next to insuring crew safety, the primary objective after a problem develops during TLI, as well as during all other mission phases, is to perform an alternate mission. Therefore, the extent of allowable deviated flight conditions must be determined in advance to insure that the desired alternate mission capability will exist. Also, due consideration must be given to the provision of reasonable initial conditions for performance of an abort maneuver. These things have been done by the development of a crew monitoring procedure which includes appropriate S-IVB shutdown limits.

The crew must be able to monitor and evaluate TLI without ground support because the maneuver can occur off the MSFN tracking range. A schematic of the basic crew monitoring technique (fig. 1) shows that an abort can be performed for S-IVB attitude rate problems, for attitude deviation problems, and for SC system problems. Because S-IVB problems normally would result in an alternate mission, only a critical SC system problem is likely to require an abort.

Several significant items can be noted about the TLI monitoring technique.

1. The TLI maneuver will be inhibited if the launch vehicle attitude before ignition is more than 10° from nominal as determined by horizon reference.

2. The TLI maneuver will be terminated by the crew for S-IVB initiated rates of 10 deg/sec.

3. The TLI maneuver will be terminated by the crew with the abort handle for attitude deviations of 45° from the nominal attitude, which are determined by onboard charts of the nominal pitch and yaw gimbal angle histories.

4. A backup to the S-IVB guidance cutoff signal will be performed by the crew if the S-IVB has not shut down at the end of the predicted burn time plus a 2σ dispersion of 6.0 seconds and if the nominal inertial velocity displayed by the SC computer has been achieved.

The charts mentioned in item 3 are shown in figures 2 and 3. The double scale on the pitch chart (fig. 3) indicates the TLI ignition gimbal angle for a 72° launch azimuth. For any other day or launch azimuth, the crew will renumber the scale by changing the zero point to the ignition pitch gimbal angle uplinked by the ground control during EPO. After an S-IVB shutdown by use of these charts, the crew will receive alternate mission midcourse requirements from the ground. The rationale for the monitoring procedures and for the determination of the previously discussed limits are documented in references 2, 3, and 4.

Although the recommended procedure for cutting off the S-IVB for attitude problems involves use of the above chart, the same end could be accomplished by the crew mentally computing differences between the actual attitude (FDAI) and values from a preflight table of attitudes at discrete times (see table I).

If a tumbled S-IVB inertial platform occurs before or during TLI, the crew may assume manual control of the burn with the hand controller. In this case, the IMU would be used to obtain reference information, and the crew charts could be used to obtain attitude information. A ground rule for manual takeover requires illumination of the guidance failure light indicating that the S-IVB platform is tumbled. The 45° attitude deviation limits are required for protection against other S-IVB malfunctions.

A comparison of the nominal pitch gimbal angle with pitch gimbal angle variations for several malfunctioning TLI burns taken from reference 5 is provided in figure 4.

5.2 TLI Abort Crew Charts

The 10-minute fixed attitude abort is designed to enable the crew to return to earth as rapidly as possible, without regard to landing location, if a catastrophic SC subsystem problem should occur which could be isolated during the TLI burn. It has been recommended that, if the situation permits, the crew should allow the S-IVB to complete TLI, at which time the ground could assist in performance of a system malfunction analysis. As yet, no single point failures are known which would require the crew to shut down the S-IVB manually and to execute this abort maneuver immediately.

The following time line has been recommended for the 10-minute fixed attitude abort. The actual time line will be presented in the Apollo Abort Summary for Apollo 11 (Mission G) to be prepared by the Crew Safety Section, Crew Safety and Procedures Branch, Flight Crew Support Division.

Time from S-IVB cutoff, min:sec, g.e.t.	Event
00:00	S-IVB burn time is recorded; THC is turned counterclockwise to initiate S-IVB shutdown; inertial velocity (V_i) is recorded from the DSKY; the four +X RCS jets are turned on
00:03	CSM/S-IVB separation occurs
00:13	The four +X RCS jets are turned off; the crew begins to pitch up ($+X_b$ down) to -r (down the radius vector), with the earth used as the visual reference to determine -r
01:00	The four -X RCS jets are turned on to initiate an evasive maneuver to provide clearance between the CSM and S-IVB for the abort maneuver
01:08	The four -X RCS jets are turned off; the crew begins maneuvers to the abort maneuver thrusting attitude (fig. 5) after having driven to the following IMU gimbal angles: OGA = 180° MGA = 0.0° IGA = ground computed in EPO
04:00	The crew selects the abort ΔV from a chart of ΔV versus V_i and S-IVB t_B (crew chart 3) and enters this value in the ΔV counter; the crew begins preparations for an SCS automatic maneuver
05:00	The COAS elevation angle is reset to 0°; the CDR adjusts his position on the couch to view the horizon through the COAS reticle image
09:30	The spacecraft is alined to the required horizon referenced attitude (fig. 5)
10:00	The SPS is ignited and the burn is controlled by SCS automatic

The crew will have a second chart, crew chart 4, to enable them to determine if sufficient time remains after the abort to perform a MCC prior to entry. In both crew charts 3 and 4, S-IVB burn time and S-IVB EMS ΔV have been provided as independent backup parameters. Typical TLI burn groundtracks and landing point loci are shown in figure 4.

If an abort is required during the first minute of the TLI burn, the crew will key V8ZE on the DSKY to display h_a, h_p, and t_{ff}, and will burn to an h_p = 19 n. mi. The abort ΔV which results in h_p = 19 n. mi. during the first minute of the TLI burn is reflected in crew chart 3. After 1 minute of the TLI burn, the abort is targeted to the contingency entry target line and the crew will read the ΔV to be burned from crew chart 3. By targeting the maneuver to the contingency entry target line, which is the same entry target line that is stored in the CMC, subsequent midcourse corrections will be targeted to the same entry target line used to determine the abort ΔV, making the abort maneuver as insensitive as possible to execution errors.

Previous studies have shown that this maneuver is relatively insensitive to execution errors in abort ΔV and ignition time. However, this abort maneuver is very sensitive to attitude errors for aborts performed after approximately 200 seconds into the TLI burn. Nevertheless, sufficient time prior to entry remains after this time to perform a midcourse correction.

6.0 LUNAR ORBIT INSERTION ABORT CREW CHARTS

During the LOI burn, failure of the SPS engine would require LM activation followed by one or more docked DPS burns to inject the SC on the transearth coast. A complete description of the LM abort modes is presented in reference 1. Monitoring of SPS systems during the burn, however, would permit termination of the LOI burn before an SPS burn capability is lost.

Because specific SPS problems during the burn can be identified and the LOI burn terminated, the SPS engine may be available for an abort maneuver after manual shutdown. In general, however, the SPS problems considered in the Apollo 11 (Mission G) mission rules are associated with decaying propellant tank pressure. For this reason, an immediate SPS abort capability would be desirable because the pressure decay might preclude SPS restarts if an extended coast period occurred prior to abort. Although the DPS has the capability to return the SC to earth for any early LOI shutdown for a July 16, 1969 lunar mission, LM activation and possibly two DPS burns are required. The 15-minute crew chart is included here because the relatively simple procedure could reduce the crew activity required if SPS problems of the type previously mentioned became evident.

Current LOI abort analyses indicate that a complete DPS backup does not necessarily exist when a hybrid translunar trajectory is flown. For a small region of LOI burn time (0 - 55 secs, duration depending on launch day) additional abort procedures are required. However, the 15-minute crew chart is still available for these launch days, although manual SPS shutdown is not recommended in the small region where the normal DPS abort procedures are not sufficient.

Basically, the procedure for use of the 15-minute crew chart is as follows.

1. After manual SPS shutdown, the crew maneuvers the CSM/LM combination to a set of gimbal angles relative to the CM IMU orientation. These gimbal angles are contained on the chart and are the same regardless of LOI burn duration.

2. The abort ΔV magnitude is read from the chart (crew chart 5) and is a function of the DVM read from the DSKY after shutdown. The burn time can be used as a backup.

3. An SPS/SCS burn is initiated at LOI-1_{IG} plus 15 minutes. Therefore, a constant time of ignition results.

4. If the SPS cannot be restarted, the normal DPS abort procedure is followed.

It is recommended that the 15-minute abort be used for LOI shutdowns prior the 3^m00^s although the chart will be extended until 4^m00^s when the abort ΔV is approximately 500 fps less than the available SPS ΔV (a nominal SPS performance is assumed). At 3^m00^s into the LOI burn, a stable lunar ellipse with a period of 15 hours has been achieved. The preabort periods in this region of the LOI burn are shown on the crew chart. For the remainder of the LOI burn, a mode III DPS abort can be initiated after one revolution, and immediate LM activation is not required. As a point of interest, if the chart is used at 3^m00^s into LOI, the total SPS burn time (LOI plus abort) is approximately 20 seconds longer than if the LOI burn had been continued to nominal shutdown.

Basically, the 15-minute crew chart provides the crew the capability to target an SPS burn onboard to return to the free-return trajectory after manual SPS shutdown.

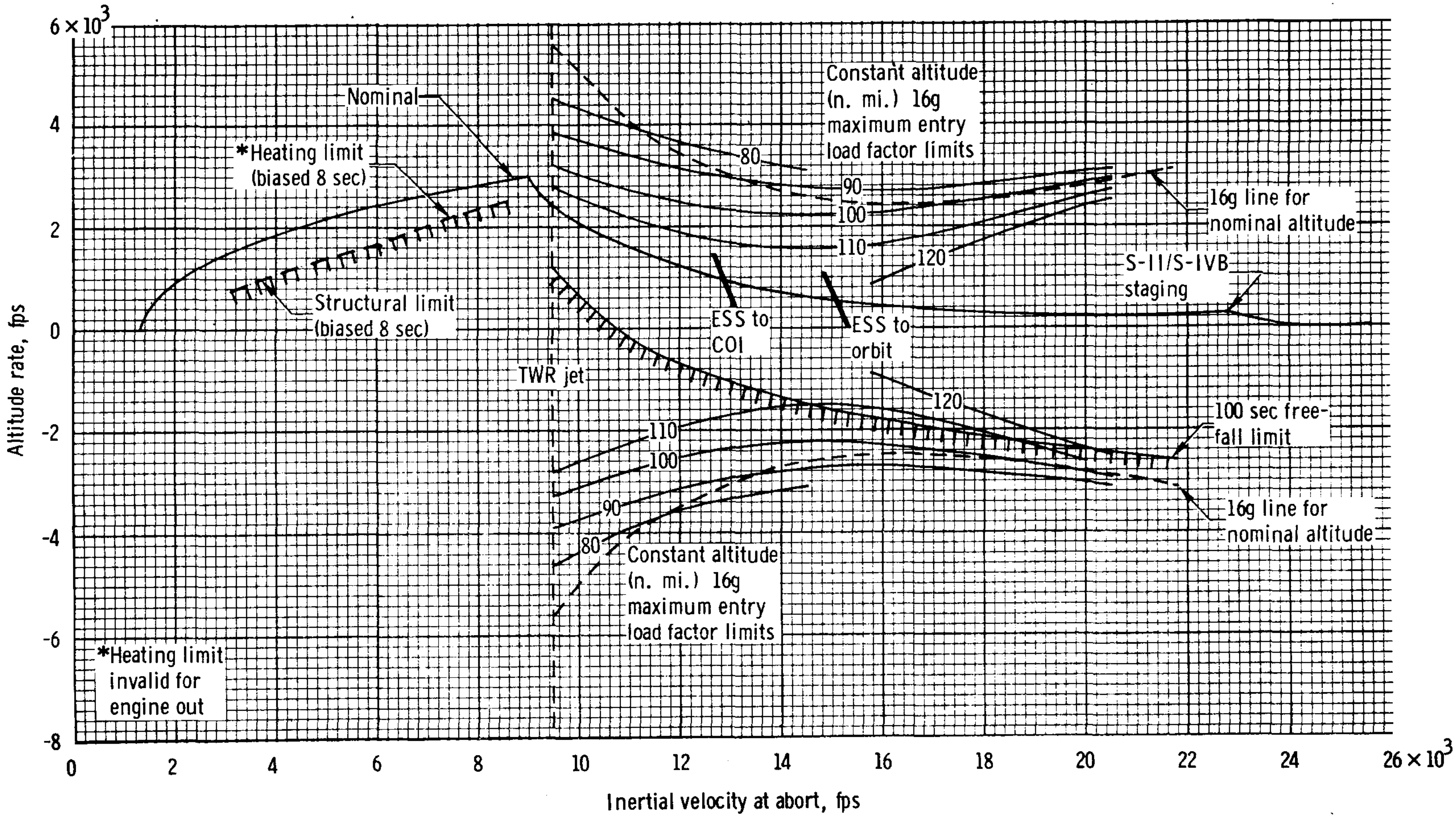
TABLE I.- APOLLO 11 (MISSION G) NOMINAL TLI,

FIRST INJECTION OPPORTUNITY JULY 16, 1969

[72.063 launch azimuth]

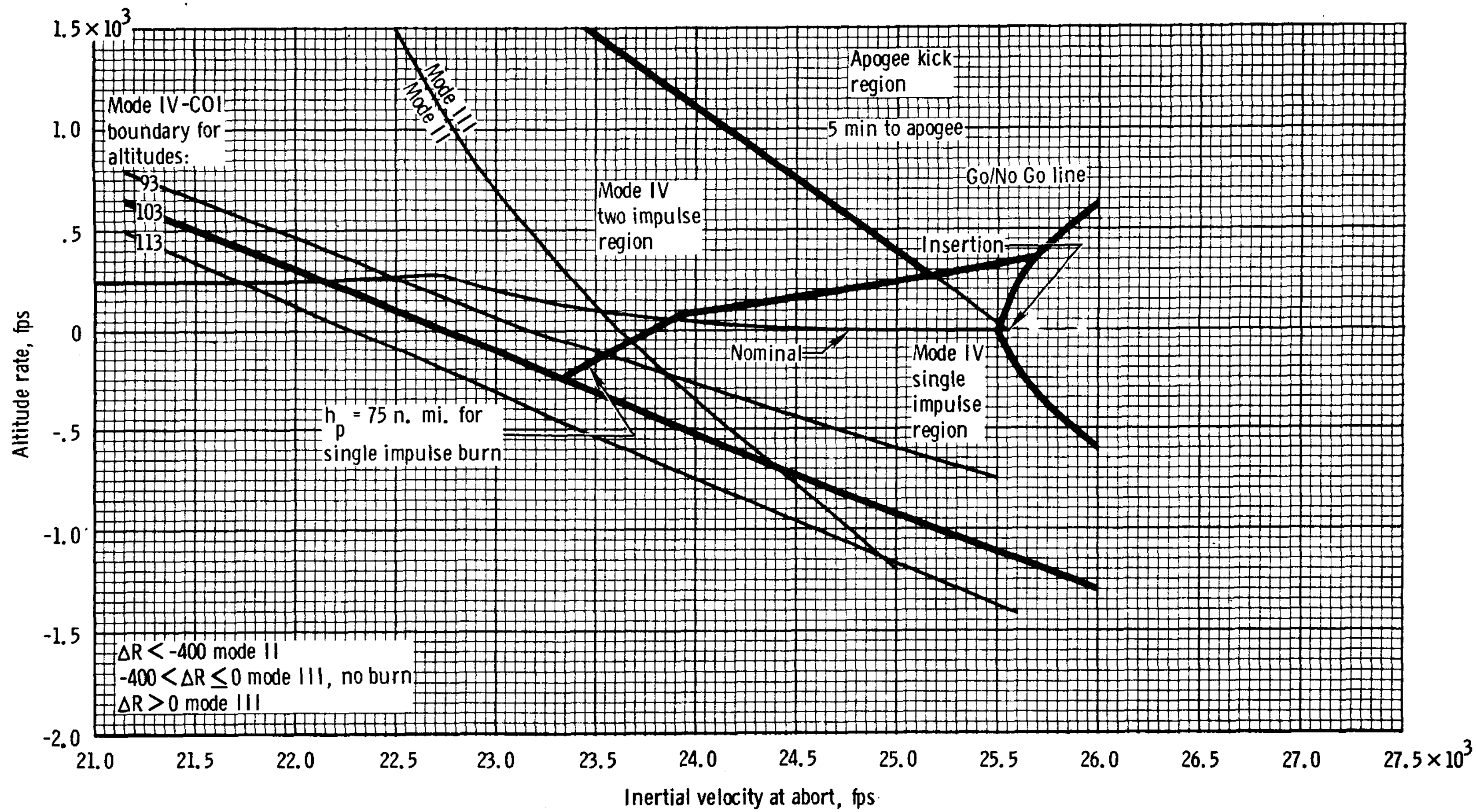
Time, min:sec	Inertial pitch, deg	Inertial yaw, deg	Inertial velocity, fps	Altitude rate, fps	Altitude above pad, n. mi.
0:00	70.6	0.1	25 554	9	107.1
0:30	65.0	0.1	26 100	-4	107.1
1:00	63.6	1.3	26 700	19	107.0
1:30	62.5	2.1	27 380	90	107.3
2:00	61.5	3.0	28 100	210	108.0
2:30	60.6	3.9	28 880	425	109.5
3:00	59.6	4.7	29 700	725	112.0
3:30	58.5	5.5	30 600	1100	116.9
4:00	57.4	6.4	31 600	1580	124.0
4:30	55.9	7.2	32 600	2200	133.0
5:00	53.8	8.0	33 650	2910	145.4
5:30	49.8	9.1	34 800	3750	162.0
5:48.33	50.0	9.0	35 563	4285	174.3

Crew chart 1. - Launch abort curves.
Henderson/FAB/MPAD
6/27/69
Final data.



Launch abort curves.

Crew chart 1. - Launch abort curves. (Concluded)
Henderson/FAB/MPAD
6/27/69
Final data.



Launch abort curves.

Crew chart 2.- Listing of planned launch trajectory parameters.
Henderson/FAB/MPAD
6/27/69
Final data.

Time from first motion, g.e.t., min:sec	SC IMU pitch gimbal angle, θ deg	DSKY displays		
		Inertial velocity, V_i, fps	Altitude rate, $\dot{h}$, fps	Altitude, h, n. mi.
00:00	90	1 340	0	0.0
00:30	86	1 389	296	0.7
01:00	69	1 845	830	3.4
01:30	48	3 026	1486	9.1
02:00	33	5 069	2195	18.1
02:15*	28	6 505	2578	24.0
02:30	24	7 869	2824	30.7
02:40.83**	21	9 030	3028	35.9
03:00	21	9 264	2657	44.8
03:30	28	9 834	2175	56.8
04:00	25	10 484	1817	66.6
04:30	22	11 232	1482	74.8
05:00	19	12 083	1178	81.4
05:30	16	13 040	908	86.6

Time from first motion g.e.t., min:sec	SC IMU pitch gimbal angle, θ deg	DSKY displays		
		Inertial velocity, V_i, fps	Altitude rate, $\dot{h}$, fps	Altitude, h, n. mi.
06:00	13	14 114	677	90.5
06:30	10	15 320	488	93.4
07:00	6	16 677	350	95.5
07:30	3	18 214	271	97.0
08:00	3	19 714	254	98.3
08:30	359	20 966	238	99.6
09:00	355	22 233	249	100.8
09:11.38***	354	22 747	270	101.4
09:30	350	22 982	196	102.1
10:00	346	23 530	104	102.9
10:30	343	24 107	35	103.3
11:00	340	24 711	-2	103.4
11:30	338	25 343	-12	103.3
11:40.10****	338	25 562	0	103.3

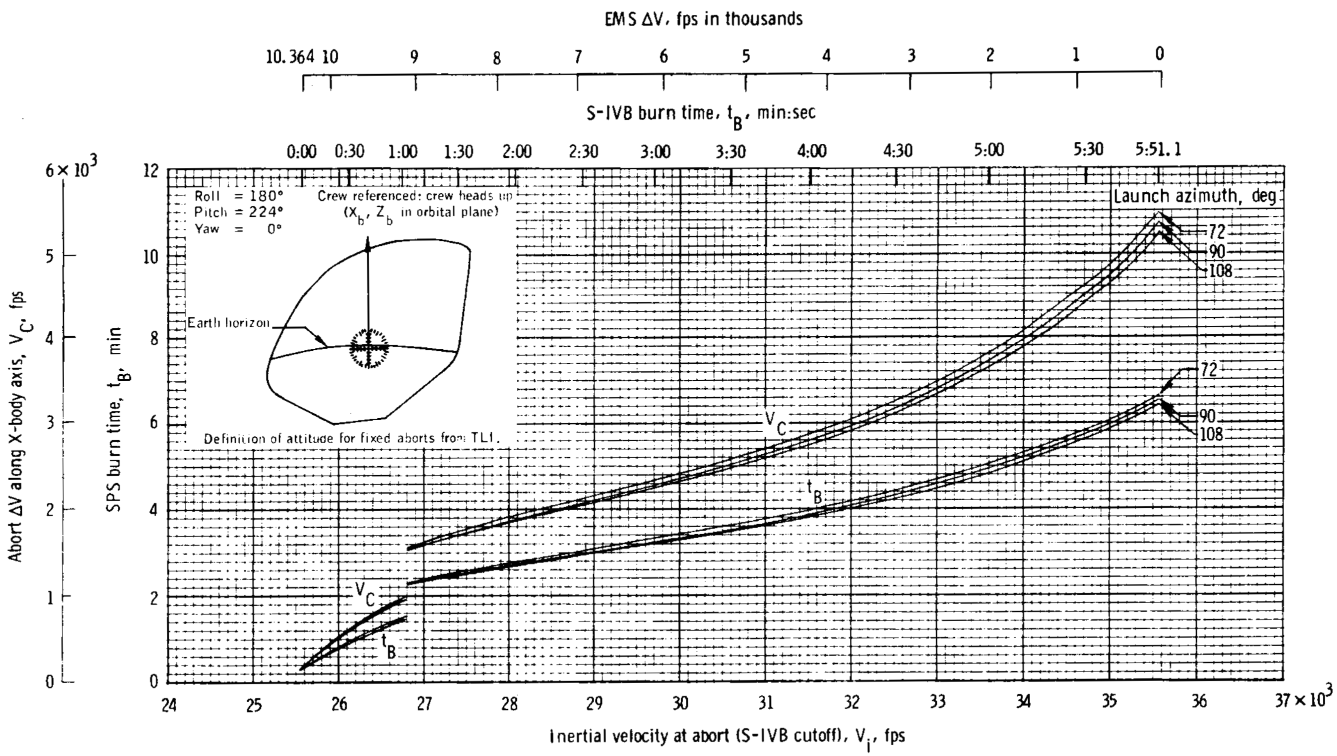
*S-IC center-engine cutoff (TB2)

**S-IC outboard-engine cutoff (TB3)

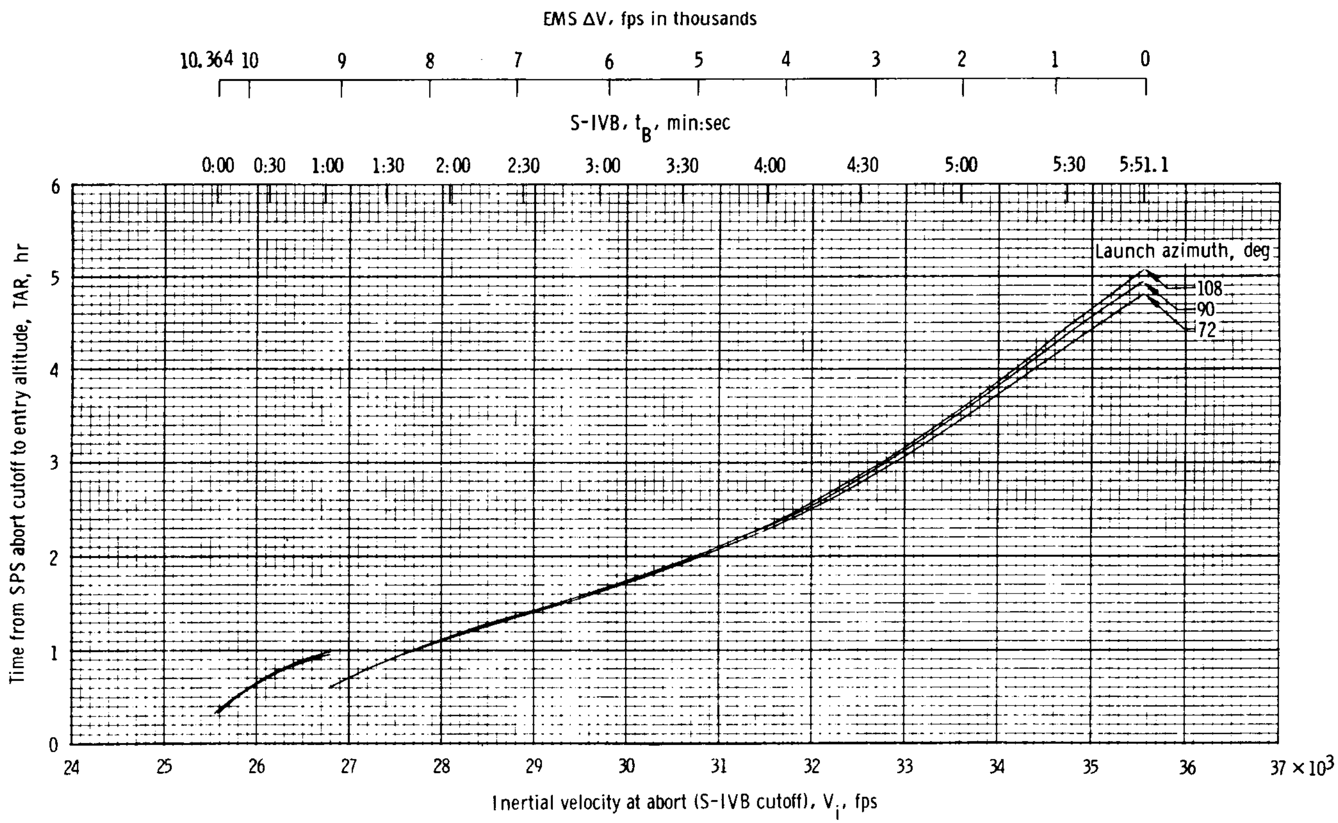
***S-II outboard-engine cutoff (TB4)

****S-IVB guidance cutoff signal

Listing of planned launch trajectory parameters.

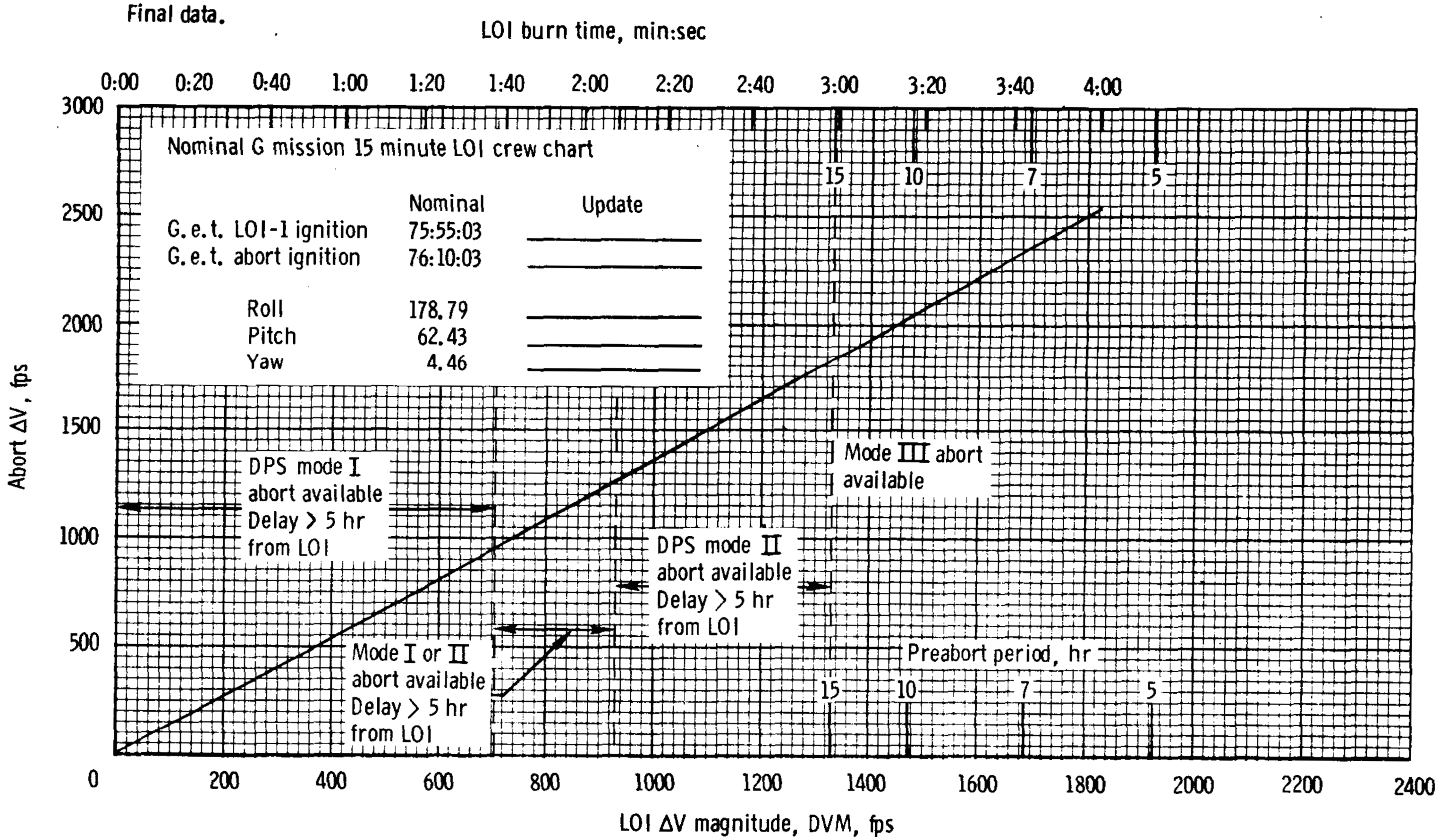


Crew chart 3.- Abort delta velocity and SPS burn time as functions of inertial velocity at abort for fixed-attitude aborts from TLI.



Crew chart 4.- Time from SPS cutoff to 400 000 feet as a function of inertial velocity at abort for fixed-attitude aborts from TLI.

Crew chart 5. - Nominal LOI 15 minute abort CSM/LM.
Foggatt/FAB/MPAD
6/27/69
Final data.



Nominal LOI 15 minute abort CSM/LM.

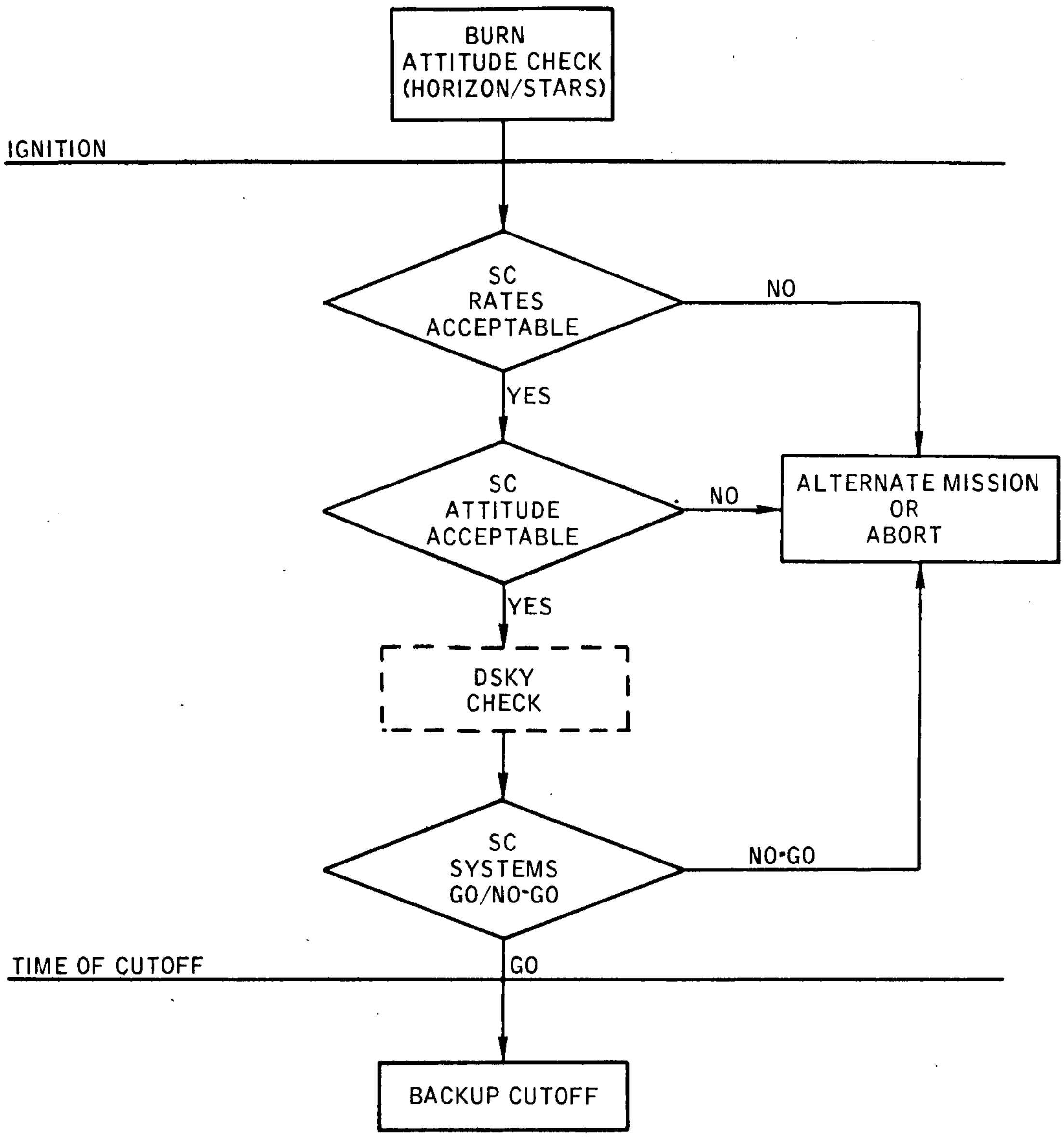


Figure 1.- Basic crew maneuver monitoring technique.

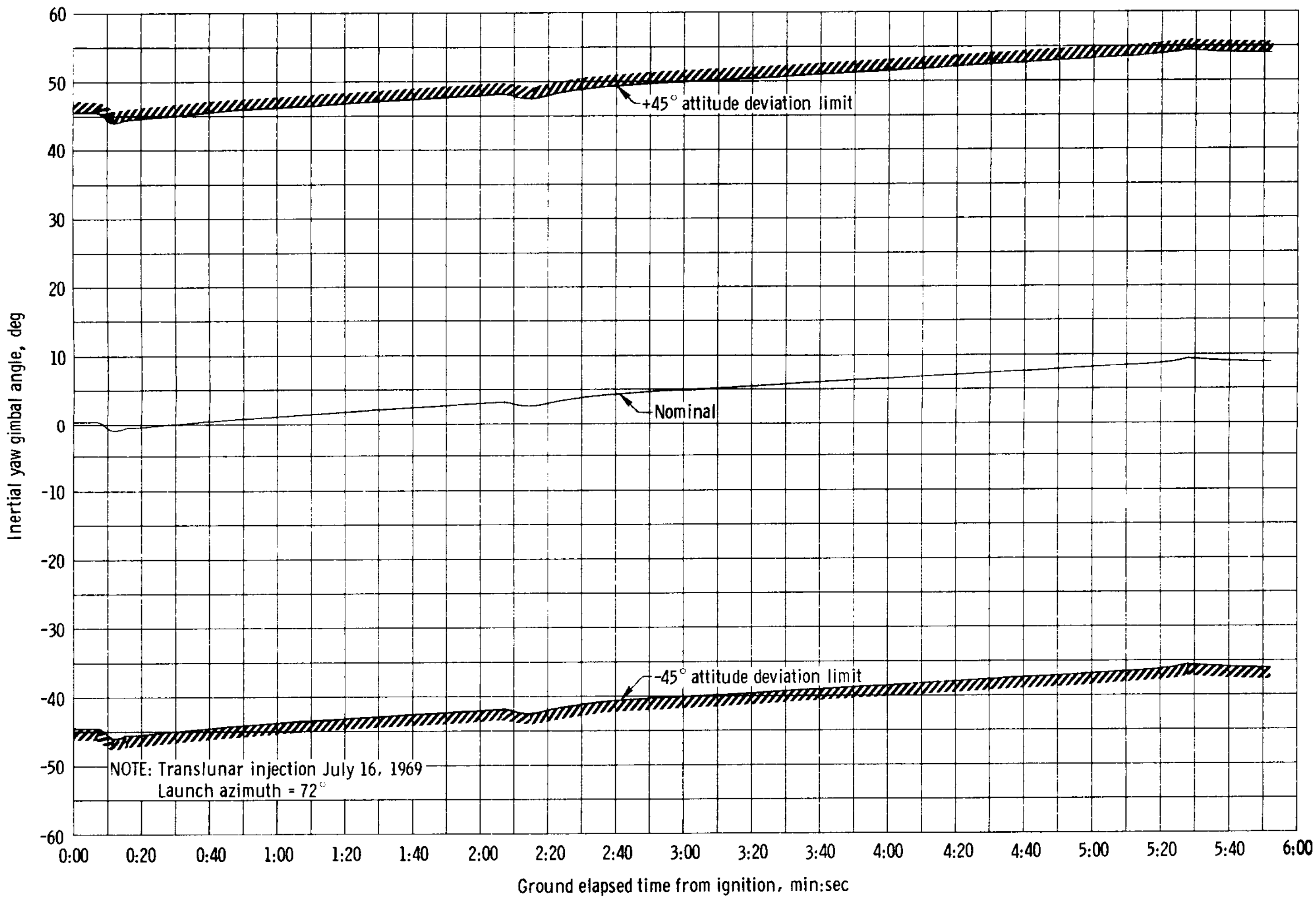


Figure 2. - TLI yaw gimbal angle history and attitude deviation limits for first opportunity.

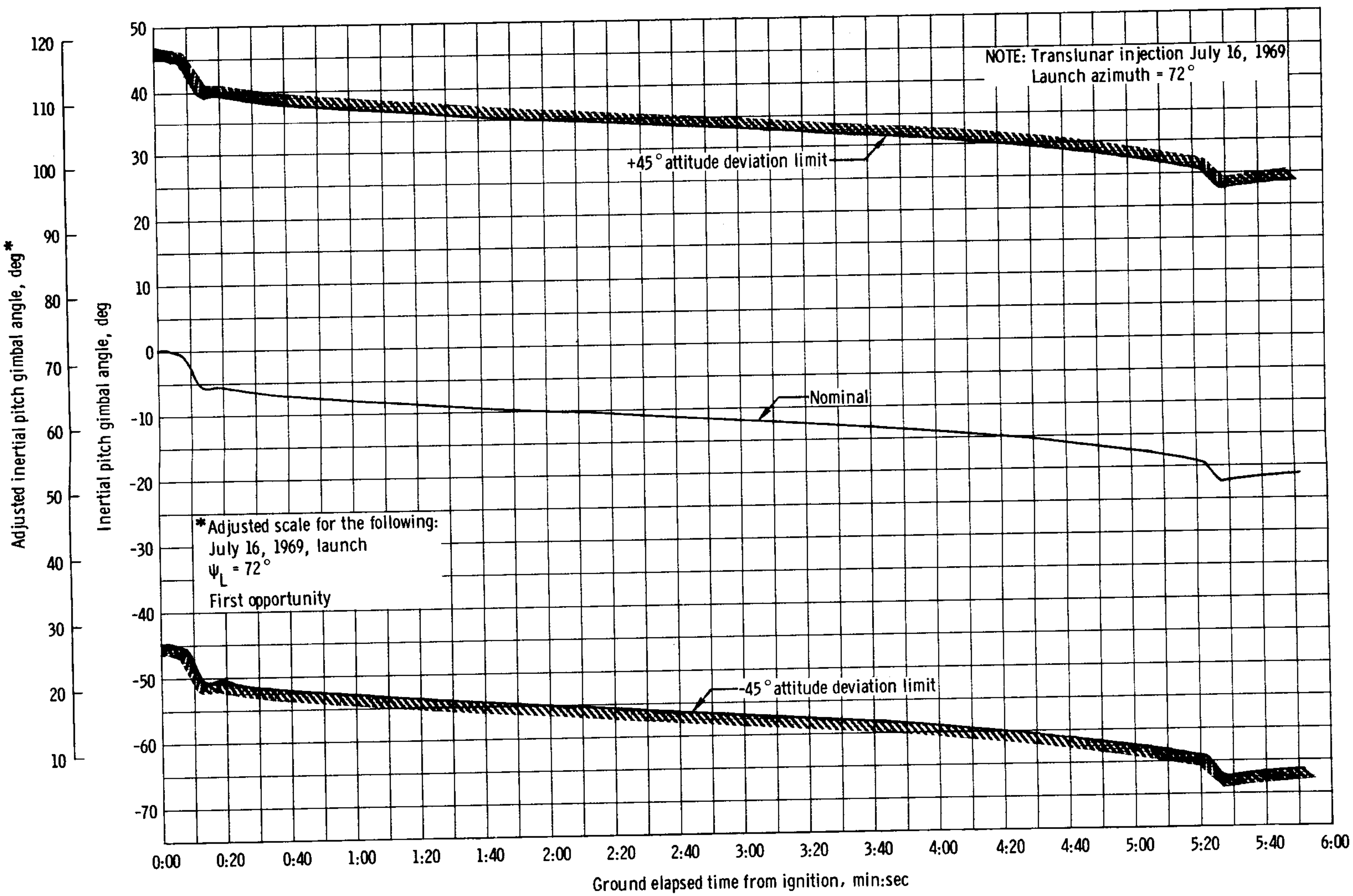


Figure 3. - TLI pitch gimbal angle history and attitude deviation limits for first opportunity.

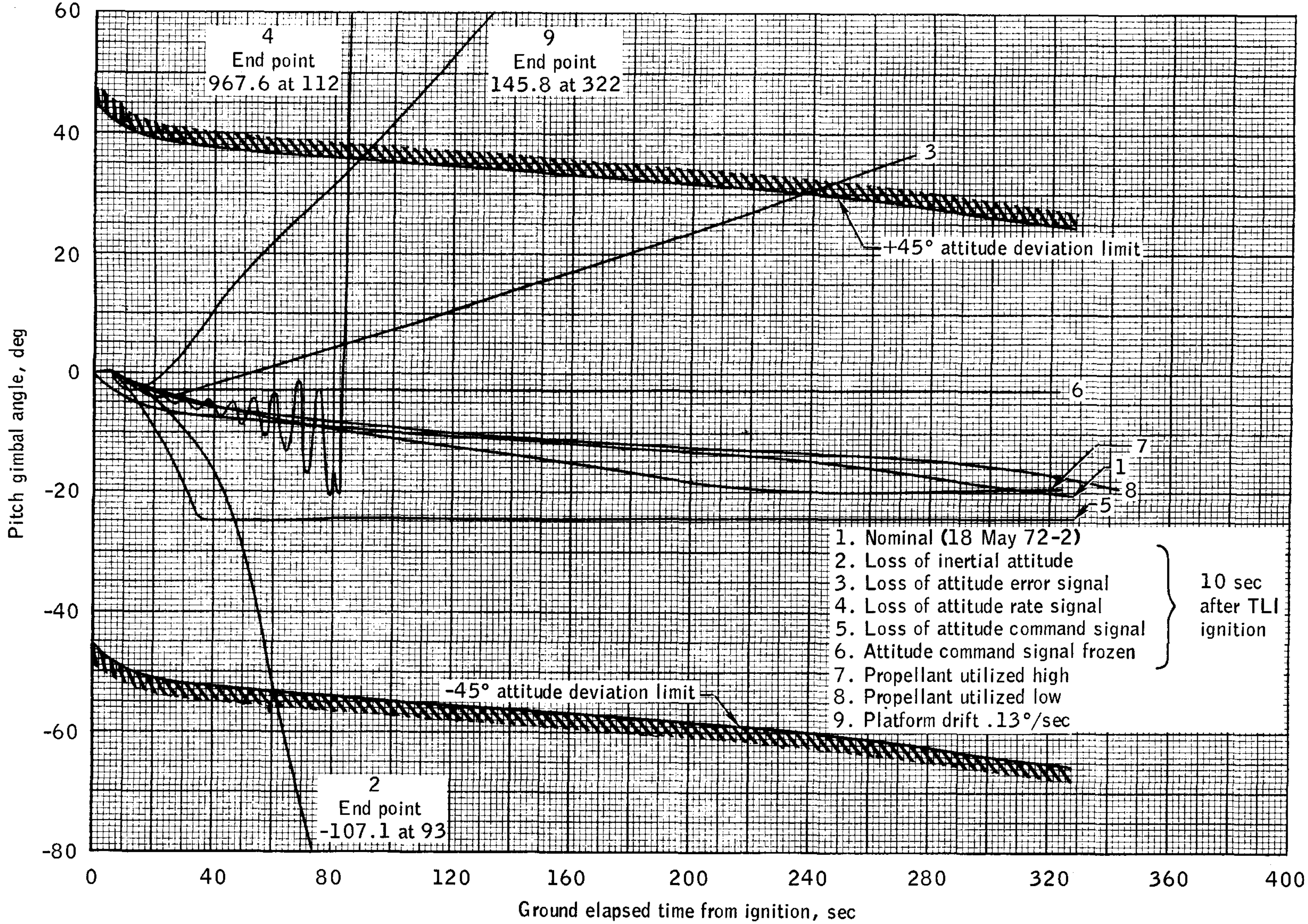


Figure 4.- Pitch gimbal angle versus ground elapsed time from ignition for various malfunctioning TLI burns.

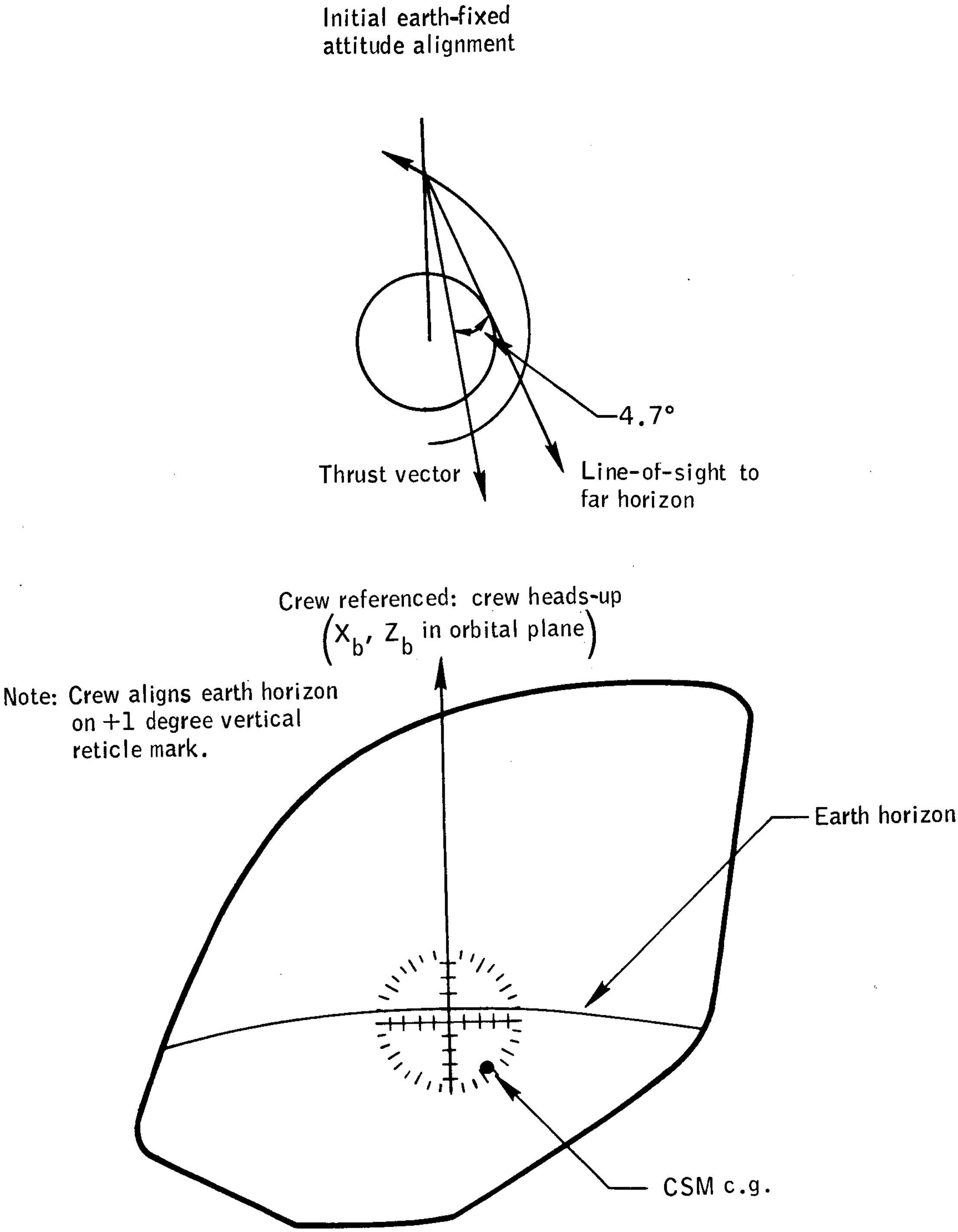


Figure 5.- Definition of attitude for fixed-attitude aborts from TLI.

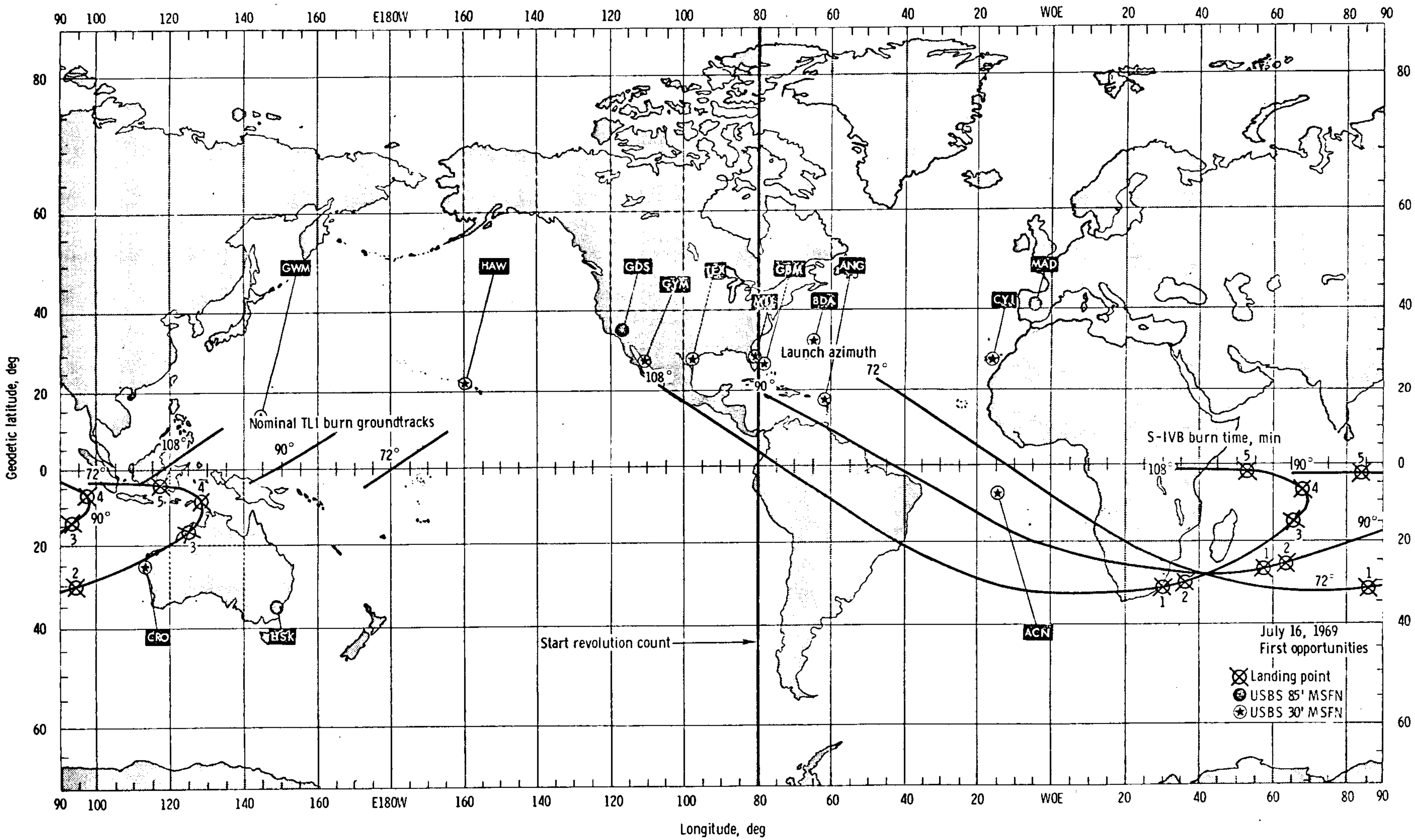


Figure 6.- Nominal TLI burn groundtracks and fixed-attitude abort landing point loci.

7.0 REFERENCES

1. Contingency Analysis Section: Operational Abort Plan for Apollo 11 (Mission G). MSC IN 69-FM-162, June 13, 1969.

2. Hyle, Charles T.: Preliminary Display Limits and Crew Monitoring Considerations for TLI, LOI, and TEI. MSC IN 67-FM-138, September 27, 1967.

3. Hyle, Charles T., and Treadway, Alexander H.: The Determination of Attitude Deviation Limits for Terminating a Nonnominal Translunar Injection Maneuver. MSC IN 68-FM-172, July 17, 1968.

4. Hyle, Charles T.: Detailed Crew Procedures for a Powered Flight Evaluation of the Translunar Injection Maneuver. MSC IN 68-FM-212, August 28, 1968.

5. Laetz, Curtis J., and Hyle, Charles T.: The Effects of TLI Malfunctions on Mission F Crew Monitoring Procedures. MSC IN 69-FM-109, April 24, 1969.

6. Technical Assistant, MPAD: F Alternate Mission Review. U. S. Government memo 69-FM-0-8, March 7, 1969.